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# Estimating original flake mass on blades using 3D platform area: problems and prospects

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This study tests how well the ITMC (Initial-/Terminal-Mass Comparison) method of Clarkson and Hiscock (2011) measures reduction specifically on blades, a largely overlooked flake type in reduction measures. We demonstrate the utility of using platform area to model the extent of reduction on retouched blades. The platform areas of 124 blades were accurately measured in three dimensions using a digital scanner. A positive relationship was observed between 3D platform area and blade mass, with greater platform areas being associated with greater masses. Multivariate regression was used to strengthen the relationship between platform area and initial mass by isolating the variables of platform, termination and indentor type as well as external platform angle. As was proposed by Clarkson and Hiscock (2011), reduction intensity can be estimated by predicting initial blade mass from the relationship between platform area and mass, and comparing this to the observed mass of a retouched blade. Our analysis returned some surprising results that raise questions about the operation of fracture mechanics, particularly for punch blades and those with focalised platforms, and the suitability of the ITMC as a holistic method of flake reduction analysis.



## 1. Introduction

Measures of reduction have become a key component in many lithic analyses in recent decades. Such measures aim to determine the extent to which artefacts have been reduced, retouched or resharpened and are employed to address questions concerning artefact life-history and curation (Andrefsky, 2006, 2009; Bamforth, 1986; Binford, 1973, 1979; Bleed, 1986; Davis and Shea, 1998; Eren and Prendergast, 2008; Iovita, 2010, 2011; Kuhn, 1995; Rolland and Dibble, 1990; Shott, 1995, 1996, 2005; Shott and Ballenger, 2007; Shott and Weedman, 2007). Reduction measures also allow analysts to explore issues of mobility, occupational intensity, technological organisation, raw material availability, subsistence and land-use patterns, by comparing reduction intensity between different levels, different sites and different raw materials (Andrefsky, 2006, 2009; Binford, 1979; Blades, 2003; Braun et al., 2010, 2008b; Clarkson, 2002; Eren, 2013; Hiscock and Attenbrow, 2003; Hiscock and Clarkson, 2008; Iovita, 2011; Kelly, 1992; Morales et al., 2013; Rolland and Dibble, 1990). Developing reliable measures of reduction intensity is therefore a valuable goal for lithic analysts seeking meaningful interpretations of intra- and inter-site assemblage variation.

Blades are a common blank form in lithic assemblages in many parts of the world and various time periods, such as the Upper Palaeolithic of Europe (Bordes and Teyssandier, 2011; Foley and Lahr, 1997; Harrold, 1989; Kozlowski, 1990) and the Microlithic of Africa and Asia (Ambrose, 2008; Clarkson et al., 2009; Mishra et al., 2013; Petraglia et al., 2009; Seong, 1998, 2008; Sherratt, 1997). Blades may be retouched into various forms, such as backed or waisted blades, or side and end scrapers. Developing a robust index of blade reduction is therefore beneficial for projects analysing assemblages with large numbers of blades. While indices such as Kuhn's (1990) GIUR have proved extremely useful for measuring retouch on flakes of various kinds, concerns have been raised about its usefulness in certain scenarios (see Eren et al., 2005). For example, it may not be well suited to measuring reduction on very long, very thin blades, where only very small retouch scars are required to reach the maximum $t/T$ ratio.

The only measure of reduction developed specifically for blades was put forth by Blades (2003), who used original thickness as a means of predicting original blade area. The ratio of area to thickness was used to determine the degree of reduction, as blade area reduced relative to thickness. Although this method achieved only low inferential power ($r = 0.73$, $r^2 = 0.53$) (Blades, 2003:147), in instances where platforms have been broken or retouched, this

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**Fig. 1.** A sample of blades analysed in the study showing the variation in morphology.

relationship could prove useful. Following the recommendation of Andrefsky (2009), who suggests that individual reduction measures should be used to model specific artefact types, this present study aims to develop a more reliable reduction measure for blades with intact platforms, as platforms are commonly preserved in the archaeological record.

A promising approach for measuring reduction on blades with intact platforms is Clarkson and Hiscock's (2011) Initial-/Terminal-Mass Comparison (ITMC) index. This index calculates reduction by predicting initial flake mass from platform area, and comparing this to the observed mass of the retouched flake, thereby calculating the proportion of mass lost through retouch. Clarkson and Hiscock's (2011) study employed 3D scans to dramatically improve the accuracy of platform surface area measurements and thereby made significant improvements on earlier attempts to predict original flake mass (Braun et al., 2008a, 2008b; Dibble, 1997; Dibble and Pelcin, 1995; Dibble and Rezek, 2009; Dibble and Whittaker, 1981; Pelcin, 1997a, 1997b, 1997c, 1998; Shott et al., 2000; Speth, 1975). This approach resulted in greatly increasing the inferential power of the resulting predictor equations ($r^2$ values of 0.85–0.95), particularly when variables that influence the relationship between platform area and flake mass were isolated (such as platform angle and platform type). Clarkson and Hiscock (2011) included a small number of blades in their experimental ITMC study (16%). While blades were not examined separately in that study, the overall success of the original mass prediction equations suggests further investigation of the performance of the ITMC on blades was warranted. This will be the focus of the remainder of this paper.

The ITMC has a number of key advantages over conventional calliper based reduction measures that make it well suited to exploring blade reduction. First of all, estimations of original blade mass are determined from platform attributes, rather than measurements taken elsewhere on the piece. Complete retouched blades tend to retain their platforms, and retouch is typically located on the lateral margins and distal end (e.g. waisted blades or side and end scrapers). This means that original platform features will commonly be preserved for analysis on retouched blades, whereas length, width and thickness may have been modified to some extent by retouch. Additionally, the ITMC has proven to have very high inferential power for a flake assemblage that included 16% blades (Clarkson and Hiscock, 2011). This provides confidence that the ITMC should also function well for blade assemblages.

To test whether 3D platform area provides a powerful means of estimating the original mass for blades, and hence whether the ITMC is suited to measuring reduction on blade assemblages, we scanned the platforms of a large number of blades made using a range of techniques and hammer types. We first describe our sample and methods and then present the results according to different blade types.

## 2. Methods and sample

A total of 124 complete blades with intact platforms were made by CC using soft hammer, hard hammer and punch technique (Fig. 1). The blades were all made from flint, and all weighed less than 100 g. While stone type was kept constant, Clarkson and Hiscock (2011) found that raw material type made no significant difference to the relationship between 3D platform area and blade mass. A wide range of different platform and termination types were also present in the sample.

Throughout the experiment, external platform angle (EPA) was measured, and platform and termination type were recorded in order to isolate the variables that influence blade size. The two platform types recognised in the analysis are shown in Fig. 2. Plain platforms refer to those which exhibit a single, flat platform surface, while focalised platforms were defined as those consisting almost entirely of a ring crack. A small number of dihedral platforms were also observed, but were excluded from the multivariate regression of platform types on the grounds that dihedral platforms are uncommon in experimental and archaeological blade assemblages.

Termination types were also recorded on each blade. Feather terminations were defined as those which taper towards the distal end resulting in a wedge shaped flake. Hinge terminations are those

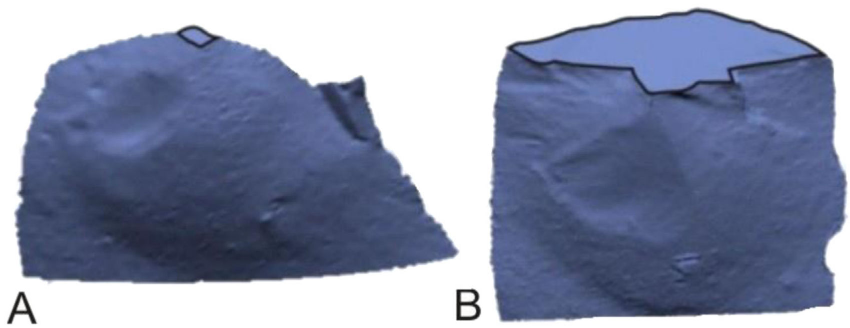


**Fig. 2.** Platform types recognised in this study. A: Focalised and B: Plain/Normal (adapted from Clarkson and Hiscock (2011)).

with rounded distal ends, created when the applied force abruptly but gently turns towards the ventral surface. Step terminations occur when the applied force dissipates within the core resulting in a sudden right-angled distal fracture. Finally, plunging (also known as overshot or outrepassé) terminations occur when the applied force dips beneath the core, terminating on the dorsal surface (Andrefsky, 2005; Cotterell and Kamminga, 1987; Cotterell et al., 1985). In the interests of maintaining a usable sample size, blades with hinge and step terminations were analysed together due to their similar distal morphologies.

Table 1 provides the proportions of platform type, termination type and hammer type represented in the experimental sample.

Platform area was obtained for each blade using a NextEngine HD 3D scanner. The platforms were scanned and the 3D images trimmed using the Scan Studio software provided with the scanner, leaving only the platform surface. This software was then used to calculate the 3D surface area of the platform image to ±0.005 inch (±0.127 mm) accuracy. Because platform area values given in the Scan Studio software calculate area for both surfaces of a two-dimensional image (i.e. the trimmed platform), it was necessary to divide the calculated surface area by two. Linear regression was then used to explore the relationship between 3D platform area and mass, and the results of isolating platform type, termination type and hammer type compared. Table 2 shows the summary statistics of the results of measuring EPA, 3D platform area and mass for all 124 blades.

**Table 1**
Proportions of platform type, termination type and hammer type represented in the experimental sample.

| | N | % of sample |
|---|---|---|
| *All Blades* | 124 | 100% |
| *Platform Type* | | |
| Plain | 60 | 48.4% |
| Focalised | 54 | 43.5% |
| Dihedral | 10 | 8.1% |
| *Termination Type* | | |
| Feather | 91 | 73.4% |
| Step/Hinge | 20 | 16.1% |
| Plunging | 13 | 10.5% |
| *Hammer Type* | | |
| Hard | 31 | 25.0% |
| Soft | 27 | 21.8% |
| Punch | 66 | 53.2% |

**Table 2**
Summary statistics of EPA, 3D platform area and mass for all 124 blades.

| | Mean | Range | Standard deviation |
|---|---|---|---|
| External Platform Angle (°) | 77.82 | 49.0–114.0 | 11.22 |
| Platform Area ($mm^2$) | 11.90 | 0.86–171.36 | 21.38 |
| Mass (g) | 8.11 | 0.77–82.09 | 12.21 |

## 3. Results

Like previous results for the ITMC on flakes, our results indicate that mass increases with 3D platform area, as shown in Fig. 3. Regression analysis returns an $r$ of 0.868 and an $r^2$ of 0.764. This result indicates that platform area alone explains roughly three quarters of the variation in blade mass. Our results explain more variation than did those of Clarkson and Hiscock (2011), who obtained an $r$ of 0.701 and an $r^2$ of 0.491 for the total flake sample.[1] This might be expected given the more limited range of flake types used in this present study. We now explore the effects of platform type, termination type, indentor type and EPA on the mass to platform area relationship for blades.

### 3.1. Platform type

As was also found by Clarkson and Hiscock (2011), platform type has a pronounced effect on the relationship between platform area and mass. When the linear regression of 3D platform area and blade mass is examined according to individual platform types (Fig. 4), it becomes clear that the extent to which 3D platform area influences blade mass varies between both platform types. Although a greater platform area results in a greater blade mass for both platform types, this impact is more pronounced in blades with plain platforms. This means that for focalised platforms, only a slight increase in platform area is required for greater mass values. In terms of plain platform types, greater increases in platform area are needed for a corresponding increase in blade mass. This pattern is to be expected, as focalised platforms tend to have similarly small platform areas, but can be associated with blades of greatly varying sizes.

In terms of the accuracy of the regression, the explanatory power of the relationship between 3D platform area and blade mass is increased when blades with plain platforms ($r^2 = 0.862$) are isolated from the entire sample of blades ($r^2 = 0.764$). On the other hand, the sample of blades with focalised ($r^2 = 0.371$) platforms suffered a loss in explanatory power compared with the entire sample. This loss in explanatory power for blades with focalised platforms can be explained by their consistently small platforms in relation to relatively large mass values. This means that while mass

[1] It should be noted that the original predictor equation presented in the study by Clarkson and Hiscock (2011) has been corrected to $-2.334 + (1.001$*Ln Platform Area$) + (0.012$*EPA$)$ as the Scan Studio software returns the surface area of both sides of the trimmed platform image. This means that the surface area values needed to be halved.

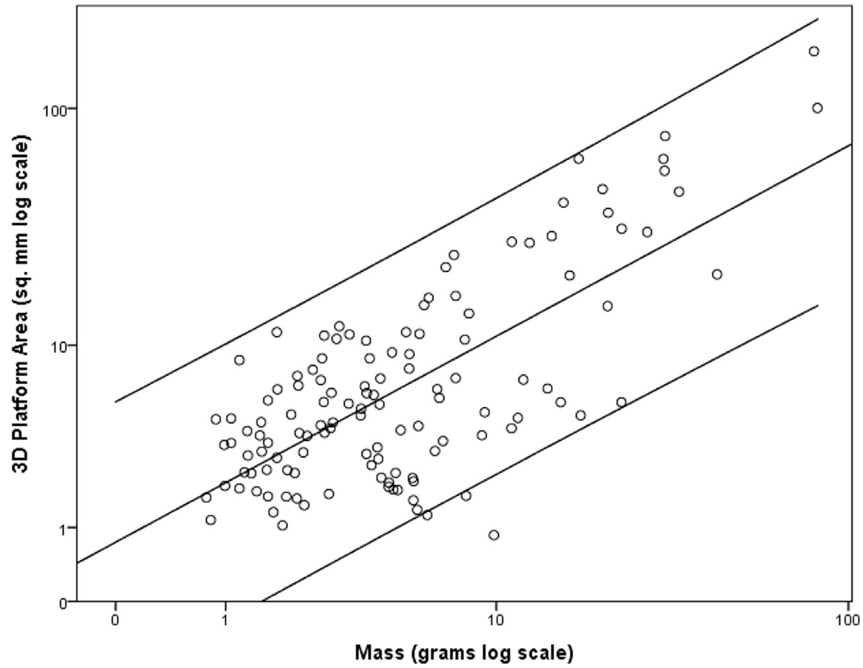


**Fig. 3.** Scatter plot showing the relationship between 3D platform area and mass for all 124 blades with 95% confidence interval lines drawn. A log scale was used on both axes to better represent the distribution.

can greatly vary, 3D platform area remains relatively constant. Therefore, platform area has a lesser influence on the mass of the blade. For plain platforms, there is an increase in explanatory power of roughly 8% compared with the original regression of the entire sample. This means that for blades with preserved plain platforms, it would be beneficial to use this strengthened regression over the original regression of the entire blade sample.

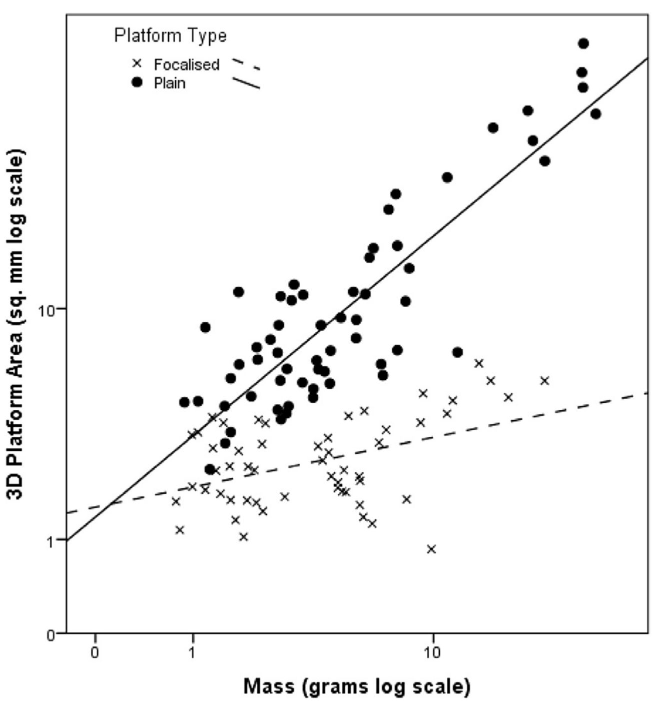


**Fig. 4.** Scatter plot of 3D platform area verses mass according to platform type, showing only blades with plain or focalised platforms. Dihedral blades were excluded due to their low representation in the sample. A log scale was used on both axes.

### 3.2. Termination type

If we similarly isolate the variable of termination type, the relationship of 3D platform area and blade mass can again be further examined. It is to be expected that blades with different terminations would display different relationships between platform area and mass. In blades with plunging terminations, much of the mass can be contained within the distal portion of the blade. With feather terminations on the other hand, the distal end typically contains very little mass.

When the platform area and mass relationship is plotted with isolated termination types (Fig. 5), the regression lines for each termination type display a different slope. This means that the variable of 3D platform area impacts the original mass of the blades to differing extents. Most notably, blades with plunging terminations can have large masses with only small increases in 3D platform area. On the other hand, 3D platform area has a greater positive impact on the mass of blades with feather, step and hinge terminations.

In terms of the explanatory power of the regressions, blades with feather ($r^2 = 0.821$) terminations have a greater coefficient of determination compared with the entire sample ($r^2 = 0.764$). This change represents a 5.2% increase in explanatory power. Blades with hinge or step ($r^2 = 0.464$) and plunging ($r^2 = 0.496$) terminations on the other hand suffered losses of inferential power compared with the original sample.

This loss in inferential power for plunging terminations can be explained by the uncertainty caused by large proportions of blade mass being from the distal end of the blade. The distal morphology of the blade core therefore has a significantly greater impact on the final mass of a blade with a plunging termination compared to those with feather, hinge or step terminations. As the mass of blades with plunging terminations are less influenced by their proximal morphology, platform area is not as suitable to explain variation in blade mass compared with the remainder of the blade sample.

Despite these losses in explanatory power, the results for feather terminations are promising. Such high coefficients of determination

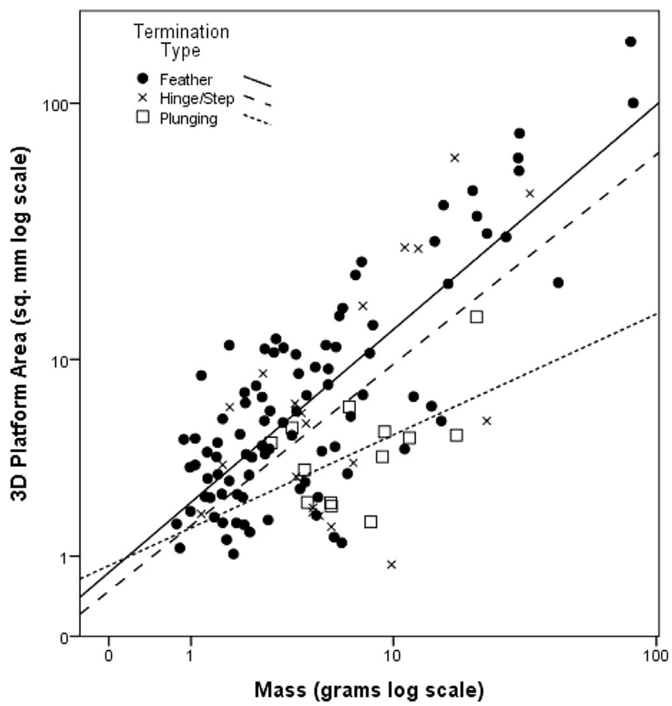


**Fig. 5.** Scatter plot of 3D platform area verses mass according to termination type, showing all 124 blades with feather, hinge/step and plunging terminations. A log scale was used on both axes.

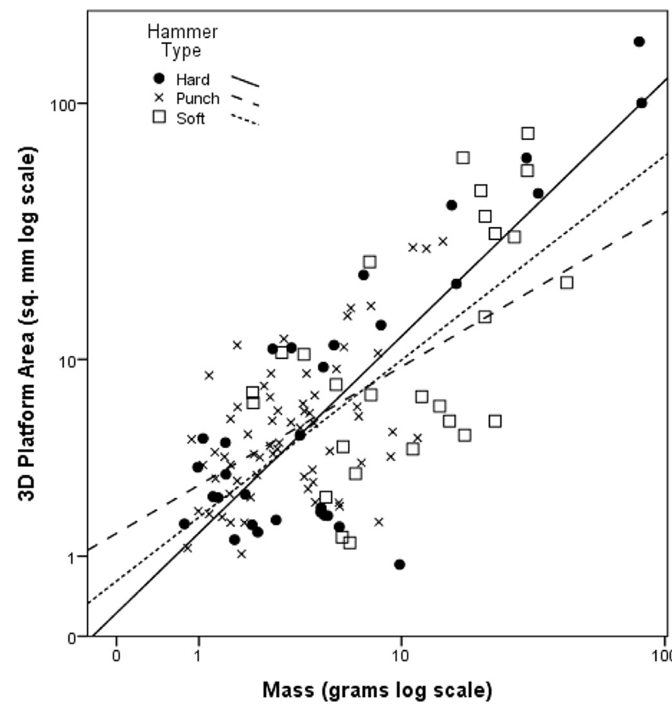


**Fig. 6.** Scatter plot of 3D platform area verses mass according to hammer type, showing all 124 blades made by hard hammer, soft hammer or punch technique. A log scale was used on both axes.

for this blade sample mean that more reliable estimates of original blade mass and therefore reduction intensity can be made. If the type of termination is still discernable in archaeological blades, this more accurate regression could be used over the original regression in order to model reduction intensity more reliably.

### 3.3. Hammer type

Hammer type, although not always readily discernable in the archaeological record (see Driscoll and García-Rojas, 2014; Magnani et al., 2014), can also influence the mass of a flake. In an analysis of the relationship between platform attributes and flake size, Shott et al. (2000) found that only flakes made with hard hammer percussion produced a meaningful platform–flake relationship. Based on Clarkson and Hiscock's (2011) method of strengthening regressions by isolating variables, multivariate regression will be used in the hopes of developing a relationship which incorporates soft and punch hammer flaking (Fig. 6).

Conforming to the prediction of Shott et al. (2000), the sample of blades produced by hard hammer percussion returned a higher coefficient of determination ($r^2 = 0.899$) than the entire sample, while the soft and punch hammer samples returned lower values ($r^2 = 0.370$ and 0.425 respectively). Additionally, all hammer types displayed regressions with similar slopes (hard = 1.67, soft = 1.18, punch = 1.29), meaning that 3D platform area influences the mass of blades with each termination type to a similar degree.

In order to strengthen the regressions of soft and punch hammer blades, termination type was added to the regression. Feather terminations are by far the most common termination type, both archaeologically and experimentally, and this sub-group of blades was therefore chosen in this multivariate regression. When the sample of blades with feather terminations is analysed, an increase in the explanatory power of the hard ($r^2 = 0.908$), soft ($r^2 = 0.503$) and punch ($r^2 = 0.657$) hammer samples can be seen. Despite this increase, it is not a sufficient change to reliably model the reduction intensity of soft and punch hammer blades.

When the same is done with plain platforms, by excluding the other platform types, we again see a change in the coefficient of determination for hard ($r^2 = 0.886$), soft ($r^2 = 0.830$) and punch ($r^2 = 0.522$) hammer blades. While the inferential power of punch hammer blades was reduced, the sample of soft hammer blades with plain platforms had significantly higher inferential power. This means that the reduction intensity of blades made by soft hammer percussion can be modelled using this improved regression if the blade has a plain platform. Contrary to the prediction made by Shott et al. (2000), multivariate regression allows the reduction intensity of both hard and soft hammer blades to be modelled using a platform–flake relationship.

### 3.4. External platform angle

Recent studies have demonstrated the influence of EPA on flake size, with larger platform angles resulting in larger flakes (Lin et al., 2013; Rezek et al., 2011). These studies also showed that concomitant increases in platform depth and EPA will result in increases of overall flake size. As platform size is partly a function of platform depth, it would be expected that EPA should influence the relationship between platform area and flake mass. When the variable of EPA is isolated, our results conform to this pattern.

Fig. 7 shows that, compared with blades with low platform angles, blades with high angles require slightly less of an increase in platform area for a corresponding increase in flake mass. This confirms the findings of Lin et al. (2013), who found that smaller increases in platform depth led to larger increases in flake size as EPA increases. In terms of the strength of the regression, blades with low platform angles displayed a stronger relationship ($r^2 = 0.882$) compared with the entire sample, while low angled blades returned a lower coefficient of determination ($r^2 = 0.516$).

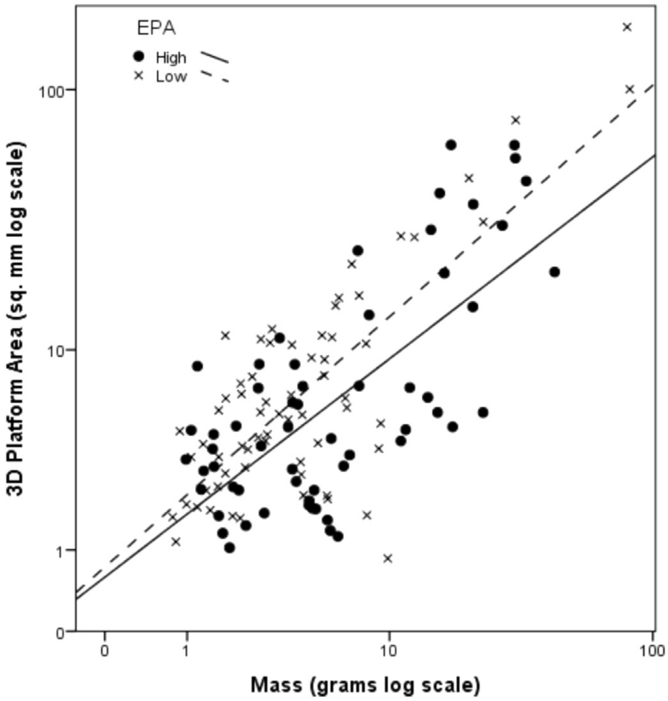


**Fig. 7.** Scatter plot of 3D platform area verses mass according to EPA, showing all 124 blades with platform angles above (High) and below (Low) the mean angle (77.82°). A log scale was used on both axes.

Therefore, blades with lower than average platform angles would best be modelled using the modified regression (Table 3).

### 3.5. Summary

The data reveal that in many instances the isolation of flake characteristics improves the explanatory power of the regressions. This heightened power leads to more reliable measures of reduction intensity which are refined for specific artefact types. Table 3 shows the strength of each isolated regression.

The most successful sub-groups of blades are those with plain platforms, feather terminations, high EPA values or those made by hard hammer percussion. On the other end of the spectrum, blades with either focalised platforms or plunging terminations stand out as the samples least suited to estimating reduction intensity from platform area. This low explanatory power is most likely due to the anomalous morphology of focalised and plunging blades.

**Table 3**
Summary of the predictor equations used to model blade mass from 3D platform area with accompanying coefficient of determination values and *p*-values.

| | Equation (3D platform area=) | $r^2$ | Significance |
|---|---|---|---|
| *All Blades* | 1.53*(mass) − 0.51 | 0.764 | >0.001 |
| *Platform Type* | | | |
| Plain | 1.79*(mass) + 1.47 | 0.862 | >0.001 |
| Focalised | 0.17*(mass) + 1.92 | 0.371 | >0.001 |
| *Termination Type* | | | |
| Feather | 1.57*(mass) + 0.34 | 0.821 | >0.001 |
| Hinge/Step | 1.37*(mass) + 0.54 | 0.464 | =0.001 |
| Plunging | 0.43*(mass) + 0.96 | 0.496 | =0.007 |
| *Hammer Type* | | | |
| Hard | 1.67*(mass) − 0.56 | 0.899 | >0.001 |
| Soft | 1.18*(mass) + 1.30 | 0.370 | =0.001 |
| Punch | 1.29*(mass) + 1.08 | 0.425 | >0.001 |
| *EPA* | | | |
| Low | 1.70*(mass) + 0.25 | 0.882 | >0.001 |
| High | 1.15*(mass) + 0.66 | 0.516 | >0.001 |

## 4. Discussion

Variation in the power of the regression models demonstrates not only the complexity of the platform area and blade mass relationship, but also the difficulty of imposing a single model to all subsets of an assemblage. The power of the regression for the entire sample serves as a baseline for the multivariate regressions. For those relationships which achieved higher inferential power compared with the entire sample, it would be beneficial to use these improved regressions. For example, the reduction intensity of a blade with a plain platform should be modelled using the improved regression ($r^2 = 0.886$) rather than the original ($r^2 = 0.764$). For those relationships which suffered a reduction in power, the regression for the entire sample can instead be used to estimate reduction intensity.

The possibility of a universal measure of reduction intensity has been on the minds of lithic analysts for some time. While some, namely Dibble (1995), view a universal measure as a very real possibility owing to controlled mechanised experiments, others are not as optimistic. Andrefsky (2009) for instance, argues that a more reliable approach to modelling reduction is for separate measures to be developed for each tool type. Upon this recommendation, only blades were analysed in this experiment, a tool type that has thus far been largely ignored. Another worthwhile avenue of research would be to apply the ITMC method to an archaeological assemblage in order to test the efficacy of such indices in archaeological contexts.

A promising finding of this study is the ability to improve the strength of the platform–flake size relationship for soft hammer blades by only considering those with plain platforms. This allows a broader application to the archaeological record. Additionally, it is interesting to note that even by analysing only punch blades with plain platforms, the strength of the regression for this indentor technique could not be improved. This finding raises questions regarding the functioning of fracture mechanics and whether or not punch flaking can be modelled alongside percussion techniques.

If we consider the explanatory power of the above relationships, what also stands out is the unusually low coefficient of determination for blades with focalised platforms. As is shown in the data, the platform area of focalised platforms explains very little of their variation in blade size. This poses a problem to lithic analysts as the platform area and flake mass relationship is an unsuitable method for modelling the reduction intensity of blades with focalised platforms.

As to why focalised platforms deviate from the pattern of the platform–size relationship, it is likely due to their consistently small platforms in relation to varying blade sizes. With such small platforms, it begs the question whether focalised platforms offer an advantage in raw material efficiency? By using less of a core's platform surface, more remains for further flake removals. As blades with focalised platforms use very little of the available platform, this could represent a strategy of raw material efficiency.

A recent study on the economy of unretouched flakes by Lin et al. (2013) explored the interactions between EPA and platform depth, and how these variables influence the ratio between edge length and mass. They concluded that the ideal strategy for optimising edge length while limiting raw material wastage was to decrease platform depth and increase EPA (Lin et al., 2013). Decreasing platform depth reduces platform area, thereby conserving more of the core's striking surface, while increasing EPA maintains flake size and edge length.

A focalised platform is the result of taking the notion of decreasing platform depth to the extreme. As is shown in the results above, a pattern exists whereby an increase in platform area results in an increase in blade mass. This is true in almost all

instances except for blades with focalised platforms. In this subgroup of blades, mass increases irrespective of increases in platform area. This would therefore suggest a threshold effect, where blades with a platform area below a certain point are not constrained by the platform–mass relationship shown above. Decreases in platform depth to the extent of producing focalised platforms could therefore result in conservation of the core's striking surface as well as blades of sufficient sizes.

It should be noted however, that it is possible that the concerted production of focalised platforms may necessitate additional platform maintenance, which may in turn offer no added benefit to efficiency. Therefore, further experimentation of cores and flakes is required to ascertain whether intentionally producing focalised platforms offers greater raw material efficiency.

## 5. Conclusion

A reduction measure developed specifically for blades has been put forward based on the ITMC method of Clarkson and Hiscock (2011). By analysing a diverse experimental blade assemblage, a strong positive relationship was observed between 3D platform area and blade mass. As platform area increased, so too did the mass of blades. It was also found that the relationship between platform area and blade mass was significantly different for blades with different hammer types, platform types, termination types and platform angles. In many instances therefore, the predictive power of this relationship could be strengthened by isolating these variables via multivariate regression. Samples of blades which were less suited to estimating reduction intensity from platform area, especially focalised blades, raise interesting questions and provide prospects for further research.

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